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The ARM Program in the Tropical Western Pacific:

1998 Update

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U.S. DOE[4] Atmospheric Radiation Measurement Program

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U.S. DOE Atmospheric Radiation Measurement Program

Abstract

The Department of Energy's Atmospheric Radiation[5] Measurement (ARM) Program was created in 1989 as part of the U.S. Global Change Research Program to improve the treatment of atmospheric radiative and cloud processes in computer models used to predict climate change. The overall goal of the ARM Program is to develop and test parameterizations of important atmospheric processes, particularly cloud and radiative processes, for use in atmospheric models. This goal is being achieved through a combination of field measurements and modeling studies. Three primary locales were chosen for extensive field measurement facilities. These are the Southern Great Plains of the United States, the Tropical Western Pacific, and the North Slope of Alaska and Adjacent Arctic Ocean. This paper describes the 1998 status of the ARM program in the Tropical Western Pacific locale.

1. Introduction

The U.S. Department of Energy (DOE) initiated the Atmospheric Radiation Measurement (ARM) Program in 1989 with the ultimate goal of improving the parameterizations of clouds and radiation used in climate models. ARM is achieving this goal through a combination of field measurements and modeling studies. A key ARM precept is that observationalists and modelers should work closely together to make use of the field data for parameterization development and validation. The ARM programmatic objectives are to produce measurements suitable for testing parameterizations over a sufficiently wide variety of situations so as to span the range of climatologically relevant possibilities. To accomplish this, highly detailed measurements of radiation and optical properties are needed at the Earth's surface, inside the atmospheric column, and at the top of the atmosphere.

[5] In the context of ARM, "radiation" refers to solar and terrestrial radiation (i.e., sunlight and radiant heat).

The primary observational method is remote sensing and other measurements made at the surface, particularly remote sensing of clouds, water vapor and aerosols. It is impossible to meet ARM's objectives, however, without obtaining a large volume of detailed in situ measurements, some of which will have to be acquired from manned or unmanned aircraft. In addition, high-quality satellite observations are needed to measure the top-of-the-atmosphere radiation.

To obtain the required in situ and surface-based remote-sensing data, ARM is making measurements, over a period of years, at three locales. Satellite data are also being acquired through cooperation with other programs. The three locales shown in Fig. 1 are the Southern Great Plains of the United States (SGP), the Tropical Western Pacific (TWP), and the North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO). The SGP covers approximately 55,000 square miles in north central Oklahoma and south central Kansas in the central United States. Implementation of the SGP began in 1992 and it is now in full operation. The TWP began phased operations in 1996 and plans to be fully operational by 2001. The NSA/AAO began implementation in 1997. ARM plans to operate each of the locales for a least 10 years. The collection of locales is called the ARM Cloud and Radiation Testbed (CART). In addition to these three primary locales, ARM may establish supplementary sites to obtain data in other regions for shorter periods of time. ARM conducts an Education Outreach Program in each locale to complement local and regional education in the areas of basic science, meteorology, and climatology.

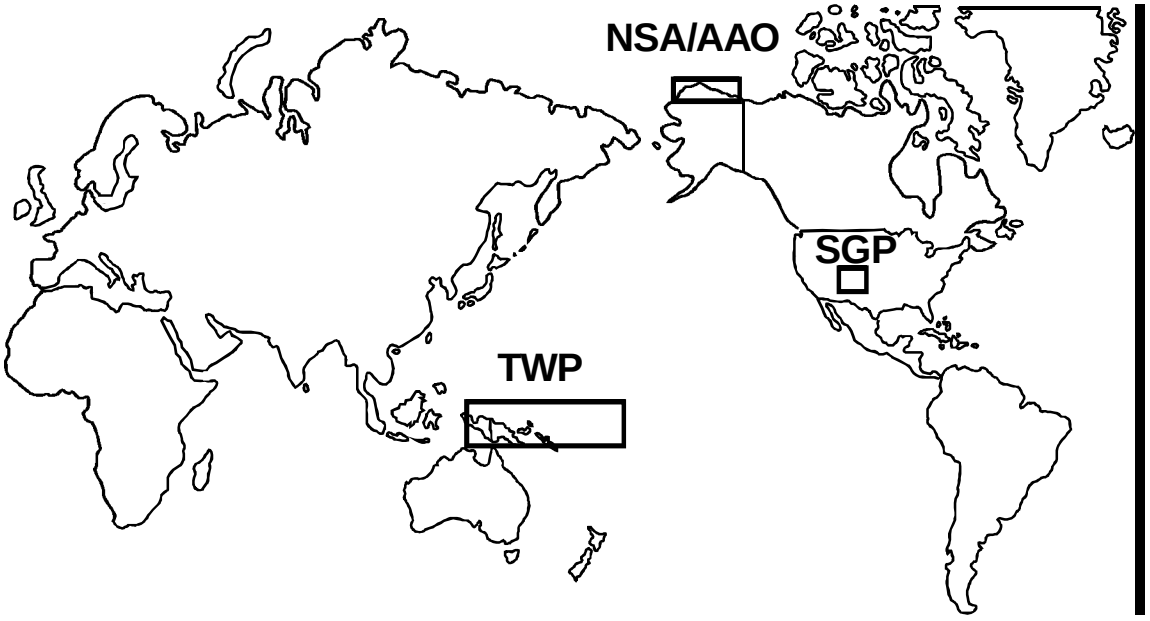

Fig. 1. Locations of the three primary ARM locales.

ARM will collect data at each locale over a period of years. One of the motivations for

continuous data collection over such a long time is to document the range of variability, as required to meet the programmatic objectives. Interesting and extreme phenomena often occur unexpectedly, and can be captured only through continuous and extended operations. In addition, continuous data collection over a period of years will begin to build up an atmospheric radiation climatology for each site.

2. The TWP Locale

The Tropical Western Pacific locale is a large expanse of tropical ocean and maritime continent lying roughly between 10^{o} S and 10^{o}N latitude and from 135^{o}E to 150^{o}W longitude (Fig. 2). The maritime continent area is largely in the southwest and the open ocean area in the northeast of the locale. Climatologically, warm sea surface temperatures, deep and frequent atmospheric convection, high rain rates, strong coupling between the atmosphere and ocean, and substantial variability associated with El Niño - Southern Oscillation (ENSO) phenomenon characterize the locale. The relationship between climatic variability in this region and variability in other areas of the planet is well known.

Scientific questions to be addressed in the TWP fall into three categories: (1) radiation budget and cloud forcing, (2) water and energy budgets, and (3) ocean-atmosphere interactions. Important and interesting scientific questions, the large expanse of the TWP locale, and logistical and financial constraints all come into play in designing a useful observational strategy. The current strategy has three distinct and critical elements:

1. Provide a long time series of basic observations at several locations that will aid in understanding intra-annual and interannual variability of surface radiation fluxes and cloud properties.

2. Augment radiation and cloud observations with intensive field campaigns to study the role of deep convection in the tropics as it affects radiative processes.

3. Devise and implement a strategy for long-term measurements of ocean-atmosphere properties and fluxes.

The first element represents the highest priority for the TWP because it relates directly to the primary scientific questions articulated by the ARM Program, and because there currently are no long-term radiation measurement sites in the TWP locale with the exception of Australian facilities in the Darwin area. Hence, the first phase of implementation for the TWP locale focuses on this element.

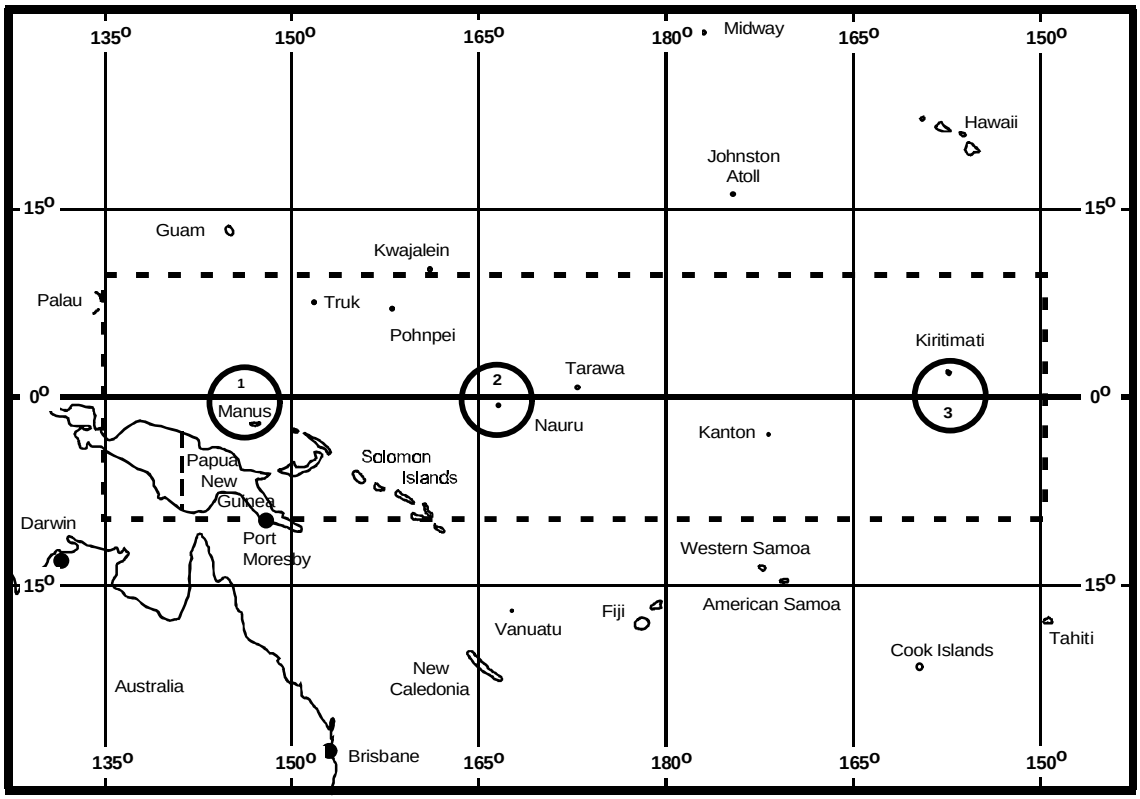

Fig. 2. Equatorial Western Pacific region showing TWP locale (dashed area) and existing and proposed ARCS sites (circles).

3. ARCS

Atmospheric Radiation and Cloud Stations (ARCS) were designed to provide the long-term basic observations required. An ARCS consists of an integrated instrument set that measures the surface radiation balance, surface meteorology, cloud properties, and some limited atmospheric quantities. In addition to the suite of scientific instruments, an ARCS contains data acquisition systems, monitoring and control systems, satellite communications, a backup electrical generator, a hydrogen generator, and other support equipment. The ARCS is housed in custom modified 20-foot seacontainers. The ARCS system is self-contained and designed to operate semi-autonomously with a minimum of on site support.

The need to measure the effect of tropical clouds and water vapor on the surface radiation budget is the main scientific driver for the set of observations made by an ARCS. Table 1 summarizes the general measurement categories and the instruments used to obtain them.

Table 1. ARCS measurements and instruments.

Measurement	Instruments
Surface radiation balance	Up- and down-looking pyranometers and pyrgeometers Sun-shaded pyranometer and pyregeometer Normal incidence pyrheliometer Up- and down-looking 9-11μm narrow field of view radiometers UV-B hemispheric radiometer Broad band (solar and infrared) net radiometer
Surface meteorology	Temperature and relative humidity sensor Barometer Optical rain gauge Propeller vane anemometer
Cloud properties	Cloud lidar Ceilometer (7.5 km maximum range) 35 GHz radar [a] Whole sky imager
Aerosol optic depth	Multi-filter rotating shadow band radiometer (total, direct, and diffuse irradiance in six 10 nm channels)
Column water	Dual channel (23.8 and 31.4 GHz) microwave radiometer
Vertical structure of the atmosphere	GPS Rawinsonde 915 MHz wind profiler with RASS[b]

a – Not yet installed at Manus

b - Operated in cooperation with NOAA[6]'s Aeronomy Lab

The ARCS Data Management System (ADaM) controls the flow of data through the ARCS. Its primary functions are data collection, storage, and processing. A major requirement for the ADaM is to minimize the loss of data. Consequently, redundancy occurs throughout the system. The heart of the ADaM is a pair of Sun workstations that backup each other. Each instrument also has a data storage buffer to further insure the preservation of data should the ADaM be inoperative for a period of time. All of the ARCS data is written to magnetic tapes and periodically shipped back to the U.S. where it is processed further, quality assured, archived, and distributed to investigators. In addition, hourly statistics of the data are calculated, encoded in a compact form, and transmitted hourly to the U.S. Scientists and engineers responsible for operating the site use these data in assessing the health and status of the instruments and in examining the general nature of the meteorological measurements being made. The hourly health and status information is transmitted via the GOES satellite system.

[6] National Oceanic and Atmospheric Administration

The ARCS has the capability to monitor the environment inside the enclosures. Some of the parameters that are monitored are temperature and relative humidity, whether the doors are open or closed, and power consumption. The power to individual systems can remotely be turned on or off and computers rebooted. These capabilities are essential to remote operations. In addition, unscheduled messages from on site operators can be sent through a Site Data Log. The INMARSAT-B communications system is used for these remote operations.

Each ARCS enclosure has dual air conditioners with humidity control to the required operating environment for the instruments, computers, and other equipment. Local commercial electrical power normally supplies power to the ARCS. A 50-kilowatt diesel generator serves as a backup. The generator system automatically starts when commercial power to the ARCS is interrupted, and shuts down when the grid power resumes. It is capable of operating continuously should commercial power not be available. The generator's 700-gallon fuel capacity provides for about one month's run time before refueling. A hydrogen generator provides the lift gas for balloon soundings.

4. Siting Strategy

An important property of the climate in the tropical Pacific is a strong east to west gradient in various climate parameters including sea surface temperature, water vapor column, and frequency of convection. High sea surface temperatures and frequent, deep convection characterize the tropical western Pacific. Toward the eastern Pacific, there is a steady decline in sea surface temperature and a corresponding decrease in the frequency of convection. An El Niño is a deviation from these typical east to west gradients. Because of this longitudinal structure and its variability it would be difficult to characterize the climate of the tropical Pacific with a single site. ARM plans to deploy ARCS at three sites to sample the structure in this region.

Figure 2 shows the existing and proposed locations of the three TWP sites. Table 2 gives the deployment schedule and status of each site. The current implementation plan calls for the TWP locale to be fully operational by 2001. ARM and SPREP[7] are working closely together in the siting, operations, public awareness, education, and other aspects of implementing the TWP program.

[7] South Pacific Regional Environment Programme, Apia, Western Samoa

Table 2. Status of ARCS sites in the Tropical Western Pacific.

	Site	Latitude	Longitude	Start Date	Status
1	Manus	2.060°S	147.425°E	1996	Operations began in Oct. 1996
2	Nauru	0.521°S	166.916°E	1998	Operations to begin in Nov. 1998
3	Kiritimati	1.87°N	157.33°W	2000	Proposed

5. The Manus Site

The first site implemented in the TWP is in Manus Province, Papua New Guinea (PNG) (Fig. 2). It was chosen to be the first site in the locale because of its location within the heart of the Pacific warm pool, the existence of a NOAA Integrated Sounding System, and the support of the PNG National Weather Service (NWS). The site is located at the NWS station at the Momote airport on Los Negros Island at 2.060°S, 147.425°E (Fig. 3).

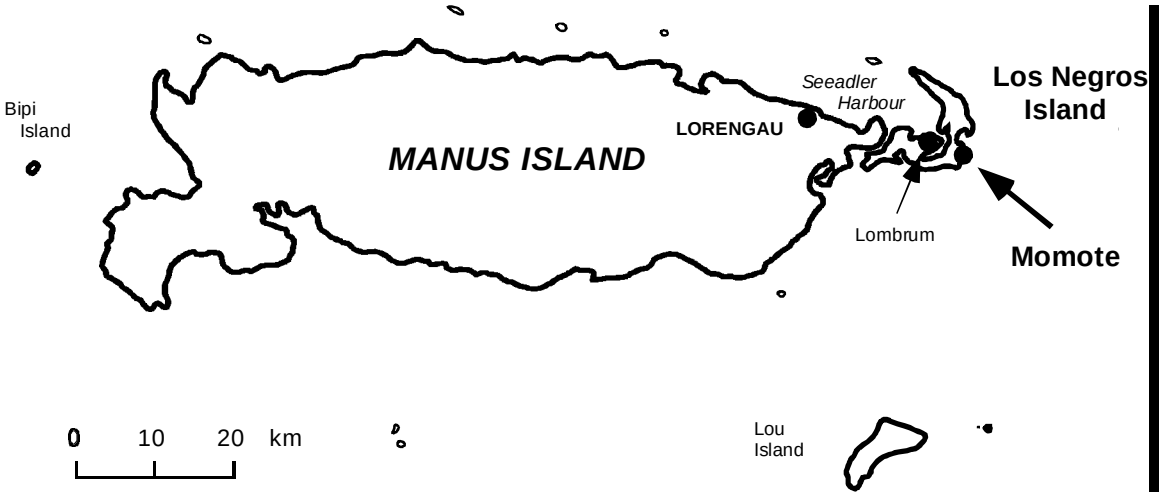

Fig. 3. Manus Province, Papua New Guinea. The ARCS is located at the National Weather Service station at the Momote airport on Los Negros Island.

The Momote site is 6 meters above mean sea level. The highest point on Manus Island is 646 m, but most of the island has an elevation of less than 200 m. The highest point on Los Negros Island is 121 m but within 3 km of the site the elevation is less than 20 m. All

equipment is located within the National Weather Service compound at Momote (Fig. 4). The siting, installation, and operation of the Momote site are a collaborative effort between ARM TWP and the PNG National Weather Service.

Fig. 4. ARCS installation at National Weather Service station at Momote airport, Manus Province, PNG.

ARCS-1 was installed at Momote during a six-week period, which began on 24 August 1996. The site was formally commissioned on 12 September and routine operations began on 8 October. NWS staff is in charge of the daily operations of the site. Assistance in performing these duties and in troubleshooting problems is provided by the TWP Operations Center in the U.S. Communications between the site and the Operations Center are conducted by phone, fax, and satellite. A REgional SErvice Team (RESET) makes periodic visits to the site to perform maintenance and calibration. These routine visits are nominally scheduled at 6-month intervals. Additional visits are made when required.

The Manus site has been operating and providing data to the ARM Experiment Center for two years. A GPS rawinsonde system was added in August 1997 and a whole sky imager was installed in August 1998. The instrument suite will be completed in early 1999 with the addition of a 35 GHz cloud radar.

6. The Nauru Site

The second site in the TWP is on Nauru Island at 0.521°S, 166.916°E (Fig. 2). We chose this site because of is location on the eastern edge of the warm pool under La Niña conditions. Installation began in late September 1998 and operations are expected to begin in mid November. We are installing all of the instruments listed Table 1. The site is located in the Denigomodu District on the northwest shore of the island near the General Hospital (Fig. 5).

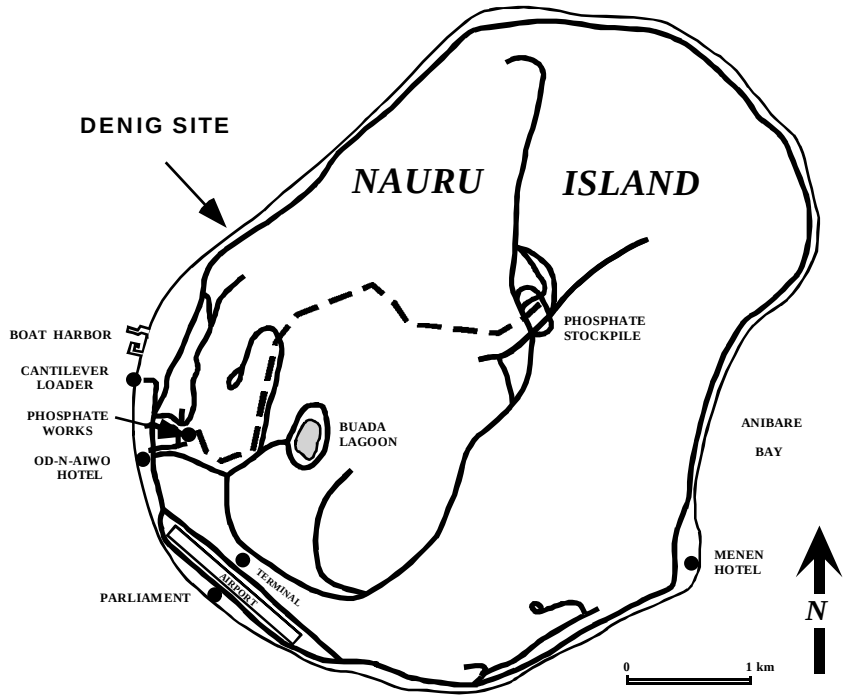

Fig. 5. Nauru Island. ARCS-2 will be located at the Denig Site on the northwest shore.

Figures 6 and 7 are panoramic views of the site three and four weeks into installation on 23 and 30 October 1998. The Nauru site is operated in collaboration with the Nauruan Department of Island Development and Industry. An opening ceremony on Nauru will be held on 20 November 1998.

Fig. 6. Panoramic view of the Nauru site three weeks into installation on 23 October 1998.

Fig. 7. Panoramic view of the Nauru site four weeks into installation on 30 October 1998.

7. The Third Site

We would like to locate our third ARCS in a region that is normally well out of the warm pool under La Niña conditions. Kiritimati Island (1.87°N, 157.33°W; Fig. 2) is the preferred location for this site. We have begun discussions with the Kiribati government concerning this possibility. A site survey trip to Kiritimati in August 1998 identified a possible site at the airport (Cassidy Field, Fig. 6). We would like to begin operations of the third site in 2000.

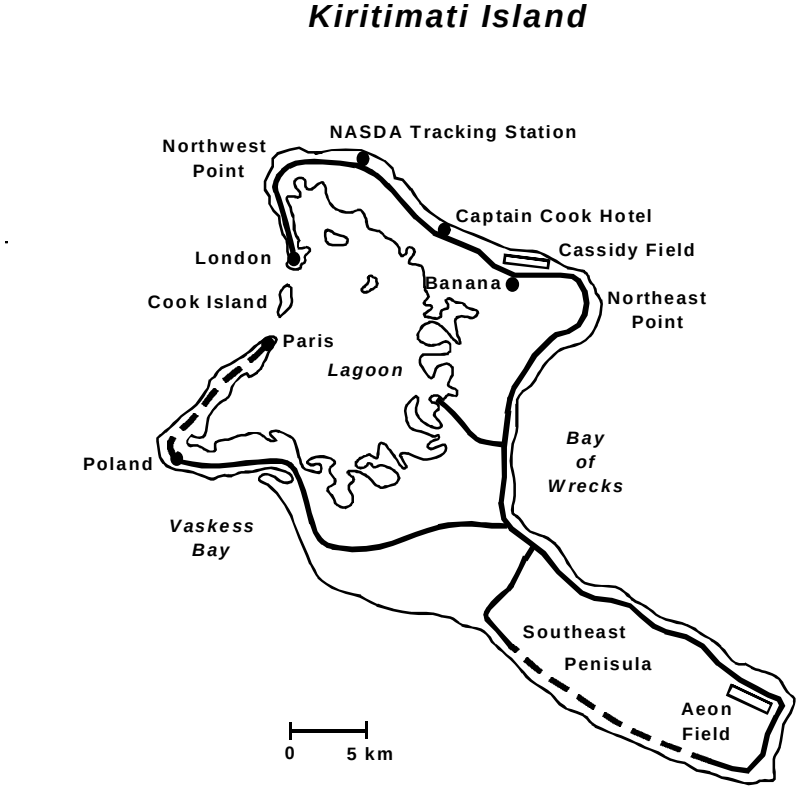

Fig. 6. Kiritimati Island.

8. Subsequent Sites

Earlier siting strategies called for two additional sites to be implemented at locations north and south of the equator in the general vicinity of 165°E. No specific sites have been identified. Currently these are not in the ARM budget, but it is hoped that funds can be obtained for them in the future.

9. Instrumented Buoys

ARM funded NOAA's Pacific Marine Environmental Laboratory to install short-wave radiometers on seven of the existing TAO buoys on the 165°E line. The radiometers were installed on the buoys at 8S, 5S, 2S, 0, 2N, 5N, and 8N during 1997. These data are providing incoming solar radiation data over the open ocean for use with the data collected from the TWP site on Nauru. The data recovery over the past year was 85 percent. The data from these buoys can be viewed on the World Wide Web at: www.pmel.noaa.gov/toga-tao/.arm/arm-data.html.

10. Nauru 99 Campaign

The first TWP campaign, Nauru99, will be conducted on and in the vicinity of Nauru Island during June 1999. The two primary scientific goals of Nauru99 are to assess the influence of the island on island-based measurements and to determine the radiative budget of the ocean around Nauru. During the campaign data will be obtained from the ARM TWP site on Nauru and from two research ships: NOAA's R/V RONALD H. BROWN and the Japanese Marine Science and Technology Center's (JAMSTEC) R/V MARAI. Each ship will carry instrumentation that basically matches the instrumentation on the island. Additional data will be obtained from the TAO buoys, aircraft, and satellites. More information on Nauru99 is available on the World Wide Web at: **Error! Bookmark not defined.**. The "Science and Implementation Plan" can be obtained from the TWP Program Office or on the web at: www.armocean.bnl.gov.

11. Educational Outreach Program

The following goals for the TWP Education Outreach Program were developed from discussions with host countries:

- to enrich primary, secondary, and college programs in the TWP region,
- to promote the development of a regional curriculum and assist with specific applications as appropriate, and
- to focus on basic science, meteorology, climate, climate change, and climate change effects relevant to the region.

Progress with the education program has been consistent, and includes successful collaborations with the Schools of the Pacific Rainfall Climate Experiment (SPaRCE; run by the University of Oklahoma), SPREP, Scripps Institute of Oceanography, and the South Pacific Sea Level and

Climate Monitoring Project (National Tidal Facility, Flinders University, Australia). We conduct in-service training for local teachers at ARCS sites, provide equipment and materials for curriculum enrichment, and sponsor teachers to attend regional education conferences. TWP scientists and technicians visit local schools to talk with students and teachers, assist teachers setting up and operating climate monitoring equipment, and lead field trips to ARM facilities.

We contributed to and sponsored the publication of two volumes of "Curriculum Modules for the Pacific Schools". These are "Climate Change and Sea Level; Part One: Physical Science" and "Climate Change and Sea Level; Part Two: Social Science". A curriculum implementation workshop will be held in Nauru on 9-13 November 1998. Another implementation workshop will be conducted in Papua New Guinea in 1999.

12. Summary

The ARM Program has begun phased implementation in the Tropical Western Pacific locale. The Manus site in Papua New Guinea began operations in October 1996. The Nauru site will be operational in November 1998. It is planned to have a third site in place, possibly on Kiritimati Island, in 2000. The data from these permanent sites will be augmented by data from satellites, research aircraft, instrumented buoys, research ship cruises, intensive operational periods, and campaigns in the region. The first campaign in the TWP, Nauru 99, is planned for June 1999. All the data from the program will be used to further the understanding of the effects of tropical clouds, water vapor, and aerosols on the Earth's radiation budget and to improve parameterizations in climate models used in assessing global climate change.

Acknowledgments

The U.S. Department of Energy's Office of Biological and Environmental Research sponsors the ARM Program. The program draws on the resources of most of the U.S. national laboratories, several universities, and other national and international agencies and contractors. The operations of the Manus site is a collaborative effort with the Papua New Guinea National Weather Service and that of the Nauru site with the Nauruan Department of Island Development and Industry. Operation of the wind profilers at Manus and Nauru is a cooperative effort with NOAA's Aeronomy Lab. The Tropical Western Pacific Program Office works closely with the South Pacific Regional Environment Programme in all aspects of the implementation and operation of the TWP program. This project would not be possible with out the cooperation and combined efforts of all these contributors.

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ARM Web Site: Further information and updates on the ARM Program can be found on the World Wide Web at: www.arm.gov.